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OPERATION SUNBEAM, SHOTS LITTLE FELLER I AND II

Project Officers Report—Project 4.1

Tissue Dosimetry

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26 March 1965

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The objectives of this project were to: (1) measure the initial neutron and gamma radiation dose from the detonation of a low-yield nuclear weapon; (2) measure and compare radiation dosage determined in air and at varying depths in animal tissue and synthetic tissue-equivalent materials; (3) compare the radiation dose at varying depths in animal tissue and synthetic tissue materials; and (4) evaluate the performance of microdosimeters under field conditions.

Results of the experiments demonstrated the feasibility of performing fairly reproducible neutron and gamma dosimetry under close-in field conditions. Tissue depth doses of both neutron and gamma radiations were measured. It was demonstrated that tissue and tissue-equivalent materials used in these studies were roughly equal in their moderating and attenuating properties. The gamma doses observed from nuclear weapons are little affected by the kinds of tissue simulants used in these studies.

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FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

OPERATION SUN BEAM

SHOTS LITTLE FELLER I AND II

PROJECT OFFICERS REPORT — PROJECT 4.1

TISSUE DOSIMETRY

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ABSTRACT

Dose determinations were performed at distances ranging from 1,000 to 1,950 feet from ground zero on the Little Feller II event and from 1,000 to 1,550 feet on the Little Feller I event. The nuclear detonation on the Little Feller II event occurred 3 feet above the ground and on the Little Feller I event approximately 20 feet above ground level.

Neutron and gamma dosage in air and at varying depths in tissue and tissue-like materials were determined. Dosimetry packages included the following dosimeters: fission foils, gold foils, sulfur pellets, silicon diode neutron dosimeters, radiophotoluminescent glass rods, film pack, and pocket chambers.

Data are presented showing the comparison of radiation dose in air and in tissue. The performance of microdosimeters in the field was demonstrated.

PREFACE

The Project Officer is indebted to and wishes to acknowledge the assistance of John M. Swartz, 1st Lt, USA, USASRDL, Fort Monmouth, New Jersey, for supplying the silicon diode neutron dosimeters used in these studies.

The Project Officer is indebted to the personnel of Group H-8 of H Division of Los Alamos Scientific Laboratory for the use of facilities and equipment on this experiment. He especially thanks Mr. Phil Lee of LASL for his cooperation.

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INTRODUCTION

Objectives. The objectives of this project were to: (1) measure the initial neutron and gamma radiation dose from the detonation of a low-yield nuclear weapon; (2) measure and compare radiation dosage determined in air and at varying depths in animal tissue and synthetic tissue-equivalent materials; (3) compare the radiation dose at varying depths in animal tissue and synthetic tissue materials; and (4) evaluate the performance of microdosimeters under field conditions.

Background. During the moratorium on atmospheric testing of nuclear weapons, significant advances were made in the area of dosimetry. Recent advances in the miniaturization of radiation dosimeters have made it possible to determine neutron and gamma dose in living tissue. Gamma dosimeters in the form of glass rods (1 mm in diameter by 6 mm in length) were developed for in vivo applications (Reference 1). Silicon diode neutron dosimeters (9 mm in diameter by 15 mm in length) are available (Reference 2).

Laboratory evaluation of the neutron and gamma microdosimeters demonstrated their suitability for use in living organisms. It was considered essential to evaluate the performance of the microdosimeters when they were exposed to the radiations from a nuclear weapon detonation. The unavailability of laboratory sources of neutron and gamma radiations prevented the evaluation of the dosimeters at the high dose rates characteristic of a nuclear detonation.

The experiment described in this report was accomplished on a nonfunded, noninterference basis.

PROCEDURE

Instrumentation. Gamma dosimetry was accomplished by means of high atomic weight radiophotoluminescent glass rods (fluorods), National Bureau of Standards (NBS) film pack, and pocket dosimeters. Packages containing the gamma measuring dosimeters

were positioned in air, at varying depths in tissue, and at varying depths in synthetic tissue materials.

Neutron dosimetry was performed using silicon diode neutron dosimeters (Reference 2), and boron and cadmium covered fission foils of Np^{237}, U^{238}, and Pu^{239} (Reference 3). Sulfur pellets and bare and cadmium covered gold foils were also used in determining the neutron dose.

The radiophotoluminescent system used in these studies to measure the gamma dose in the mixed neutron and gamma field was described in Reference 4. High atomic number silver metaphosphate glass rods, composition by weight 46 percent Al PO_4, 23 percent $Ba_3(PO_4)_2$, 23 percent K_3PO_4, and 8 percent Ag_3PO_4, were used. Exposure of the radiophotoluminescent (RPL) rods to ionizing radiation causes loosely bound electrons to be freed and to migrate through the glass. Some of the electrons are trapped by interstitial silver ions to form photoluminescent centers. The dosimeter was read by exciting the photoluminescent centers with ultraviolet light and converting the emitted orange-yellow fluorescence to an electric current through the use of a photomultiplier tube.

The RPL rod is a relative system, that is, it must be calibrated against standard gamma detecting instruments exposed in known radiation fields. A calibration curve was prepared at the Nevada Test Site by exposing the RPL rods to known doses of gamma radiation from a Co^{60} source. The measured fluorescence was plotted against known exposure dose in constructing the dose response curve. Dose response curves were prepared for the Bausch and Lomb microdosimeter reader and the Turner fluorometer used in these investigations. The readings obtained in air and in tissue from the RPL rods exposed to the nuclear detonations were read against the dose response curve.

The self-indicating pocket dosimeters were read directly. The pocket dosimeters were calibrated against a 125-curie Cs^{137} source. The appropriate correction factor was applied to each dosimeter.

The NBS film packs were processed by the Air Force Radiological Laboratory, Wright-Patterson Air Force Base. Densitometer readings were performed and compared to NBS film packs exposed on a Cs^{137} calibration range.

Neutron dosimetry was performed by exposure of fission foils to the radiations from the nuclear detonation and counting the resulting radioactivity in a fission foil counter. Fission foils and gold foils were calibrated at Los Alamos Scientific Laboratory's Omega

East Reactor. The calibration foils were flown to the Nevada Test Site and counted on the same fission foil counter as the experimental foils.

Thermal neutron activation of bare and cadmium covered gold foils was determined by scintillation counting. A $\frac{1}{16}$-inch thick aluminum filter was used to eliminate the 0.96-Mev Au^{198} beta.

Sulfur pellets were returned to the Radiochemical Section of Biophysics Branch, Kirtland Air Force Base, New Mexico. The sulfur pellets were beta counted in a low background (less than 0.5 counts/min) counter.

The silicon diode neutron dosimeters were read at the Nevada Test Site. Neutron dose in rad was obtained by comparing the scale reading against a previously prepared calibration graph.

Sources of Samples. Animal Tissue. The animal tissues exposed in this experiment consisted of enbalmed sheep carcasses. The animals were sacrificed under nembutol anesthesia by exsanguination. Dosimetry packages containing fluorods, silicon diodes, NBS film packs, fission foils, bare and cadmium covered gold foils, and sulfur pellets were attached by sutures to the aorta. The dosimetry packages occupied a position within the body ranging from the first lumbar to the second sacral vertebrae. Identical dosimeter packages were placed on the front and back surface of the sheep carcasses and suspended free in air. The measurements thus recorded represent the measured entrance dose, the midline dose, and the exit dose. These doses should be compared with the air dose which occupied the same relative position as the midline package. In addition, dosimetry packages, consisting of fluorods, silicon diodes, and sulfur pellets, were placed in the vagina, and the right and left ear canal of the experimental subjects. After the dosimeters were implanted, the surgical openings were sutured and the carcass embalmed with 10-percent formalin solution. The carcasses were wrapped and sealed in polyethylene bags. In the field the carcass was supported in the normal anatomical position (Figure 1).

Tissue-Equivalent Plastic Cylinders. Three cylinders of tissue-equivalent plastic were purchased (Reference 5). The tissue-equivalent plastic used in the cylinders contained approximately the same proportions of carbon, hydrogen, oxygen, nitrogen, and trace elements as are found in human muscle tissue. The cylinders were 25 cm in diameter by 30 cm in length. Each cylinder contained a 5.1-cm diameter by 15-cm deep center well, a 1.9-cm diameter by 12.5-cm deep lateral well, and six 0.65-

cm diameter by 15-cm deep wells. The six small wells were on the opposite end of the cylinder from the center well. The lateral well was on the side of the cylinder, 7.5 cm from the end of the cylinder containing the small wells.

Tissue-Equivalent Gel. A tissue-equivalent gel (Reference 6) was prepared with ammonium formate, ethylene glycol, agar, calcium chloride, sodium chloride, and water. The gel was autoclaved at 105° C. The molten gel was cast in polyethylene carboys of 25-cm diameter by 30-cm height. Dosimetry packages were inserted at various depths in the gel.

Tissue-Equivalent Manikin. A specially developed tissue-equivalent plastic manikin, containing a human skeleton, was purchased from the same source as the plastic cylinders. The composition of the tissue-equivalent plastic skeleton was the same as that of the cylinders. The plastinaut was exposed at a distance of 1,300 feet from ground zero on the Little Feller II event only. The plastinaut contained a cavity for dosimeters in the abdomen. Sulfur pellets, fluorods, and silicon diodes were positioned in the abdomen.

Air Dosimetry. Air dosimetry packages were supported on wooden supports used to hold the animal carcasses and cylinders. The air dosimetry packages were positioned 50 cm from the nearest mass of tissue or tissue-like material.

Location of Stations. The experiment was designed to encompass the range of biologically significant radiation doses. Three stations were selected with line-of-sight view of ground zero. The nearest station was 1,000 feet from ground zero. The intermediate station was 1,300 feet from ground zero. The distant station was 1,950 feet from ground zero on the Little Feller II event. Because of interfering terrain this station was moved forward to 1,550 feet on the Little Feller I event.

Recovery of Specimens. All stations were recovered at H+75 minutes on the Little Feller II event and at H+3 hours on the Little Feller I event. The dosimeters were removed from the animal carcasses, plastic manikin (Little Feller II only), tissue-equivalent plastic and gel cylinders, and the air dose measurement packages. Dosimetry readings were begun at H+5 hours on both events and continued on a round-the-clock basis until completed. The fission foils were counted first, followed by gold foils. Fluorods, silicon diodes, and pocket dosimeters were read after the threshold and activation foils were counted.

RESULTS

In Table 1, the ratio of neutrons in each of four energy intervals is given. This table provides a comparison between the two events and also between a low-yield nuclear detonation and the Sandia Pulsed Reactor (SPR), a Godiva-type critical assembly. The major difference between the spectrum of the nuclear weapon and that of a pulsed reactor is in the abundance of neutrons above an energy level of the latter case. There are some four times as many neutrons with energies greater than the case of the pulsed reactor. Neutrons in the range are approximately abundant in the nuclear weapons spectra as in the pulsed reactor spectrum.

Table 2 summarizes the experimentally determined neutron and gamma doses on the two shots. Neutron dose was measured by threshold detectors and silicon diode neutron dosimeters calibrated against a Godiva spectrum. Pocket chambers, NBS film pack, and radiophotoluminescent glass rods were employed in arriving at an estimate of the gamma dosages.

Table 3 summarizes the findings of neutron and gamma dose determinations on the Little Feller I and II events. Silicon diodes and threshold detectors were used for measuring neutron dose. The silicon diodes were employed on the Littel Feller II event only and consistently yielded higher results than the threshold detectors. The silicon diodes were calibrated against a Godiva neutron spectrum rather than weapons spectrum and this may be responsible for the variation noted.

In Table 4 are presented the results of fast neutron flux and gamma dose determinations on the Little Feller II event. These data were obtained from dosimetry packets inserted in natural body orifices in the case of biological tissue and existing cavities in the plastic manikin.

Table 5 presents the experimentally determined thermal neutron flux as measured by the bare gold-cadmium covered gold method. The thermal neutron flux may be converted to rad dose by multiplying . The thermal neutron rad dose was in all cases less than 1 rad and is not included in the doses given in the tables.

Table 6 summarizes the ratio of bare to cadmium covered gold foil counts on the Little Feller II event. The moderation of neutron flux by hydrogenous material is readily apparent from the values reported. The similarity between tissue and the tissue-equivalent plastic and gel used in these studies is equally obvious.

In Table 7 data are presented relative to the effect of shielding on the RPL rod gamma

detectors. The rods encased in polyethylene tubing consistently exhibited a higher apparent gamma dose.

Figures 1 through 4 illustrate the dosimeters and instrumentation setups employed in these studies. Figures 5 and 6 are views of the field stations.

DISCUSSION

Comparison of gamma dose as measured on Little Feller I and II using NBS film pack and lithium-lead shielded glass fluorods in air, tissue, and tissue-equivalent materials are in general agreement, though certain discrepancies are obvious. At all locations the glass fluorod dose is higher than the dose determined by the NBS film packs.

Neutron and gamma air dose measurements, reported in Table 2, reveal little correlation between the two shots even though they were of the same approximate yield. Preshot dose calculations determined by the methods given in Reference 7 give calculated neutron doses at distances of 1,000, 1,300, 1,500, and 1,950 feet from ground zero

The experimentally measured data on the Little Feller I event agree well with the predicted values. Only the 1,950-foot station on Little Feller II, however, falls near the predicted dose. It is suggested that the best explanation for this anomaly is that the 1,000- and 1,300-foot stations on Little Feller II were shielded. The 1,950-foot station on Little Feller II was on a slight elevation and, consequently, did not experience the shielding seen by the two closer-in stations.

In spite of the shielding it is believed that the data on Little Feller II can be used for purposes of comparing in-air and in-vivo neutron dose.

In the case of gamma dosimetry, neither Little Feller I nor II yielded data in accord with the predicted values of 145, 173, 48, and 23 roentgens at distances ranging from 1,000 to 1,950 feet from ground zero. It appears that this anomaly is due mostly to inaccuracies in the code within 2,000 feet of ground zero.

The gamma dose recorded by the glass fluorods was some 1.2 to 1.8 times higher than the gamma dose detected by the NBS film pack. It is believed that the discrepancy between film pack and fluorod measured gamma dose is due in part to: differences in calibration, energy dependency, and thermal neutron sensitivity. The results of the measurements should be considered relative, and comparisons should be made between in-air and in-vivo gamma dose measurements determined with the same type of detectors. The in-air neutron to gamma ratio was found to be 2.3, using gammas as determined by the NBS film, and 1.5 if fluorods were used as the basic gamma determinations. There was also

disagreement between the gamma dose as measured by the pocket air ionization chambers and gamma dose as determined by the fluorod or film pack. It is probable that the discrepancy is due to the dose rate and energy dependency of the pocket chambers.

The marked energy dependency and thermal neutron sensitivity of unshielded glass fluorods is evident in the data presented in Table 7. Published results of thermal neutron sensitivity of unshielded glass fluorods (Reference 6) have indicated that 1-rad-equivalent gamma response is produced by 3×10^8 thermal neutrons per square centimeter.

Data presented in Table 7 reveal the marked differences in response between lithium-lead shielded and unshielded glass fluorods. The neutron component leads to apparent doses which are 1.5 to 2.5 times higher than those given by the shielded fluorods.

The fast neutron flux as measured by sulfur pellets is rapidly attenuated by tissue and tissue-equivalent materials as is shown in Tables 4 and 5. Conversely, there is a significant buildup of thermal neutrons at similar positions. It is noted that there was not a significant difference in fast neutron fluxes between midline and exit measurement locations. Apparently, the intervening tissues between entrance and midline thermalize the majority of neutrons. This is borne out by the results of experiments in which sulfur pellets were placed in the right and left auditory canals of the sheep cadavers. The fluxes determined under these conditions (in which the sulfur pellet on the right or entrance side of the animal was within 1 cm of the surface, while on the left or exit surface some 10 to 12 cm of bony and soft tissues intervened) revealed doses on the right side midway between entrance and midline doses. On the left side of the animal, the dose was roughly equivalent to that at midline.

Comparison of results between neutron and gamma doses measured in tissue and in tissue-equivalent materials indicate general agreement. Certainly, under the conditions of field testing, tissue-equivalent materials have much to recommend them. The rather wide variations in experimental results are to be explained on the basis of the problems of precise dose measurements in the field as opposed to the same measurements made in the laboratory. Subsequent experiments in the laboratory, using the same type of dosimeters and the Godiva-type reactor at the Sandia Pulsed Reactor Facility, have shown that, under laboratory conditions at least, a high degree of precision is possible using the dosimeters employed in these studies. The unsuitability of existing methods of determining neutron dose in the field was demonstrated during these studies. Existing methods of neutron dosimetry are laborious, time-consuming, and difficult to accomplish under field

conditions. Fission foil counting methods are not well adapted to use under any conditions other than those normally encountered in the laboratory. The silicon diode neutron dosimeters are still in an early stage of development and require additional studies before they may be reliably used in determining neutron exposure dose. The diodes used in this study had been calibrated against the Godiva fission spectrum at the Sandia Pulsed Reactor Facility and appear to be strongly neutron energy dependent. It should be pointed out, however, that the Hurst threshold dosimetry system is only strictly applicable for dose determination, as calibrated, if the neutron environment being measured is similar to a fission spectrum. This condition obviously was not met under field conditions.

It was possible to measure neutron and gamma depth dose in tissue and tissue-equivalent materials. The variation between embalmed carcasses and tissue-equivalent materials was relatively small.

The agreement of results obtained when gamma depth dose was determined with plastic and gel materials is considered noteworthy. This is especially true in light of the relative cost of the two materials. The plastic tissue-equivalent cylinders cost several dollars per pound compared to a few cents per pound for the gel tissue-equivalent material.

The disagreement between fluorod and air ionization chamber results may be due to the dose rate dependency of the air ionization type device. Glass fluorods are useful gamma dosimeters in a mixed neutron and gamma field only when adequate precautions are observed to prevent neutron effects.

CONCLUSIONS

The results of the experiments accomplished on the Little Feller I and II events of Operation Sun Beam demonstrated the feasibility of performing fairly reproducible neutron and gamma dosimetry under close-in field conditions. Tissue depth doses of both neutron and gamma radiations were measured. It was demonstrated that tissue and tissue-equivalent materials used in these studies were roughly equal in their moderating and attenuating properties. The gamma doses observed from nuclear weapons are little affected by the kinds of tissue simulants used in these studies.

Unprotected personnel exposed at distances beyond 500 yards would probably have survived the radiation exposure on the Little Feller II event. Observation of blast and thermal damage to the stations during recovery operations did not reveal any evidence of damage even at the 1,000-foot station. On the Little Feller I event personnel would probably have been able to survive and continue their duties if they were not closer than

500 yards from ground zero. It does not appear probable that either event would have caused the immediate incapacitation of personnel located at the indicated distances. Lethal doses of radiation exposure would have been sustained by most, if not all, personnel located 1,300 feet from ground zero, but in neither event was sufficient dose delivered to have rendered the majority of personnel nonoperational within minutes to hours postdetonation.

TABLE 1 SUMMARY OF FREE AIR FLUX MEASUREMENTS ON SHOTS LITTLE FELLER I AND II

Event	Distance	× 10^{10} n/cm²				Ratio = Neutrons in energy interval / Neutrons 4 kev			
		0.004 Mev	0.750 Mev	1.5 Mev	2.5 Mev	4 to 750 kev	0.75 to 1.5 Mev	1.5 to 2.5 Mev	2.5 Mev
	ft								
Little Feller I	1,000								
	1,300								
	1,500								
Little Feller II	1,000								
	1,100								
	1,300								
	1,700								
	1,950								
Godiva II Critical Assembly	—								

TABLE 2 FREE AIR NEUTRON AND GAMMA DOSE MEASUREMENTS ON SHOTS LITTLE FELLER I AND II

Event	Distance	Neutron	Neutron	Gamma	Gamma	Gamma
	ft	rad *	rad †	r ‡	r ¶	r ‖
Little Feller I	1,000					
	1,300					
	1,500					
Little Feller II	1,000					
	1,300					
	1,950					

* Neutron dose determined by threshold detector method.
† Neutron dose determined by silicon diodes.
‡ Gamma dose determined by NBS film pack.
¶ Gamma dose determined by glass fluorods in Li-Pb canisters.
‖ Gamma dose determined by pocket dosimeter.

TABLE 3 IN-VIVO DOSE MEASUREMENTS

Shot	Distance	Sample	Neutron	Neutron	Gamma	Gamma	Gamma
	ft		rad *	rad †	r ‡	r ¶	r §
Little Feller I	1,000	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
	1,300	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
		Plastic					
	1,500	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
		Plastic					
Little Feller II	1,000	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
		Plastic					
	1,300	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
		Plastic					
	1,950	Sheep					
		Entrance					
		Midline					
		Exit					
		Cylinder					
		Gel					
		Plastic					

* Threshold detector method. † Silicon diodes. ‡ NBS film pack.
¶ Glass fluorods in Li-Pb canisters. § Pocket dosimeter.

TABLE 4 IN-VIVO FAST NEUTRON FLUX AND GAMMA DOSE MEASUREMENTS, SHOT LITTLE FELLER II ONLY

Distance	Sample	Sulfur Neutrons $\times 10^{16}$	Glass Fluorods	Silicon Diodes	Air Ionization
ft			r	rad	r
1,000	Vagina		360	350	200
	Right ear		315		
	Left ear		150		
1,300	Vagina		195	210	135
	Right ear		175		
	Left ear		130		
	Plastic manikin				
	Abdomen		161		
	Abdomen		163	50	
	Abdomen		132	45	
	Abdomen		150		
1,950	Vagina		50	155	
	Right ear				
	Left ear		42		

TABLE 5 SUMMARY OF THERMAL NEUTRON AND SULFUR NEUTRON FLUXES

Shot	Distance	Specimen	Thermal Flux	Sulfur Flux
	ft			
Little Feller I	1,000	Free air		
		Plastic cylinder		
		Sheep, midline		
	1,300	Free air		
		Plastic cylinder		
		Sheep, midline		
	1,500	Free air		
		Plastic cylinder		
		Sheep, midline		
Little Feller II	1,000	Free air		
		Sheep, midline		
		Sheep, exit		
		Plastic cylinder		
		Gel cylinder		
		Sheep, vagina		
		Sheep, entrance		
	1,100	Free air		
	1,300	Free air		
		Sheep, midline		
		Sheep, exit		
		Plastic cylinder		
		Gel cylinder		
		Sheep, vagina		
	1,700	Free air		
	1,950	Free air		
		Sheep, midline		
		Sheep, exit		
		Plastic cylinder		
		Gel cylinder		
		Sheep, entrance		
		Sheep, vagina		

TABLE 6 SUMMARY OF RATIO OF BARE TO CADMIUM COVERED GOLD FOILS ON SHOT LITTLE FELLER II

Distance	Specimen	Ratio = Bare Au Foil Count / Cd Covered Au Foil Count
ft		
1,000	Free air	1.85
	Sheep, entrance	4.50
	Sheep, midline	4.5
	Sheep, exit	4.3
	Plastic cylinder	4.4
	Gel cylinder	4.0
1,300	Free air	1.7
	Sheep, entrance	4.9
	Sheep, midline	8.3
	Sheep, exit	6.4
	Plastic cylinder	6.2
	Gel cylinder	7.7
1,950	Free air	1.9
	Sheep, entrance	4.3
	Sheep, midline	4.6
	Sheep, exit	5.2
	Plastic cylinder	4.8
	Gel cylinder	7.6

TABLE 7 COMPARISON OF RPL ROD RESPONSE WHEN ENCAPSULATED IN LITHIUM-LEAD SHIELDS AND IN POLYETHYLENE TUBING

Location	Lithium-Lead Shield	Polyethylene Shield
	r	r
1,000 feet		
Air dose	450	850
Cylinder, plastic	310	625
Cylinder, gel	368	600
Internal	375	580
Exit	260	380
1,300 feet		
Air dose	175	290
Plastinaut		
Trachea	190	270
Mediastinum	140	260
Cylinder, gel	165	275
Internal	200	290
Exit	125	215
1,950 feet		
Air dose	35	85
Cylinder, gel	37	65
Internal	42	105
Exit	35	80

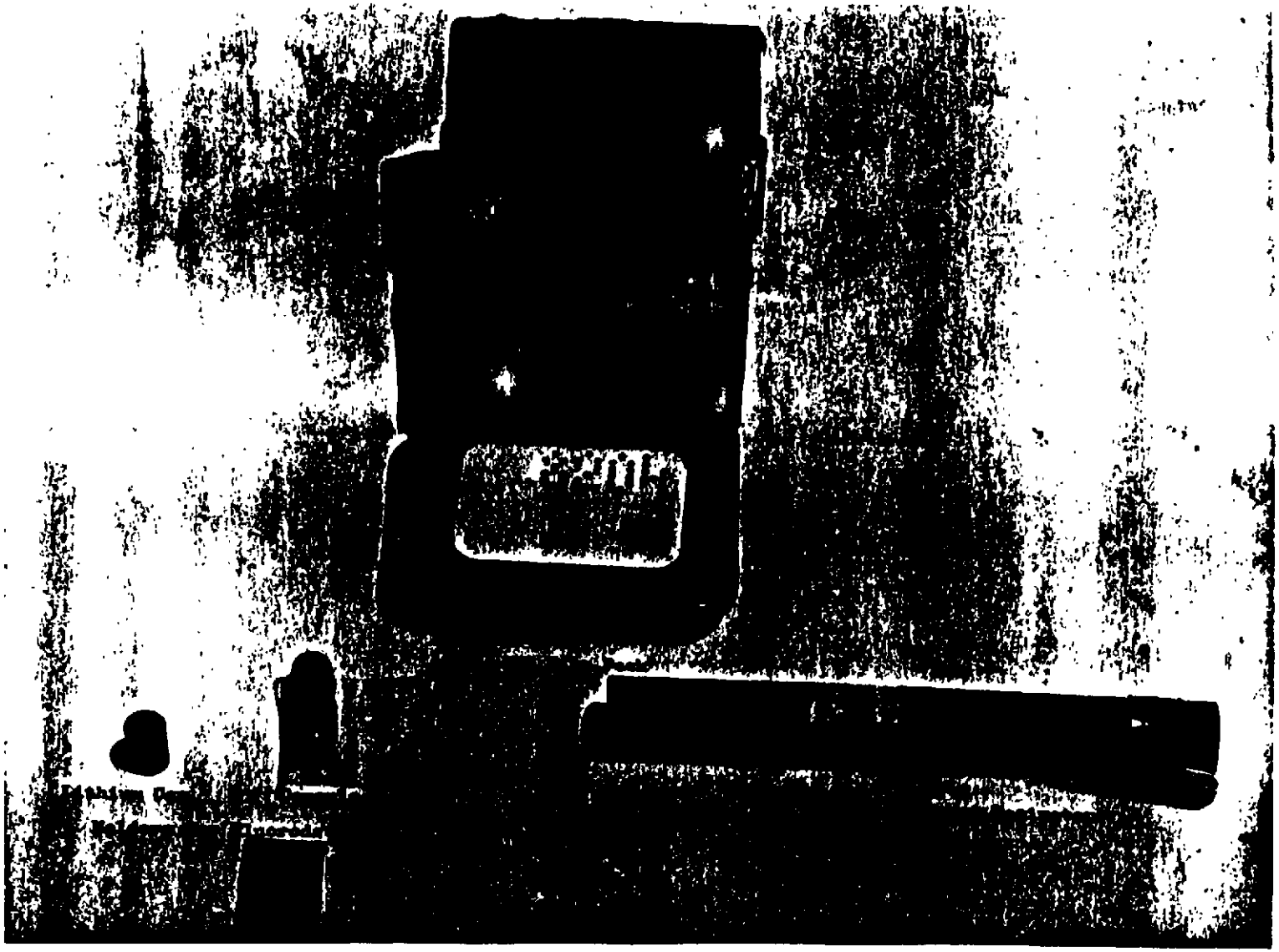

Figure 1 Gamma dosimeters. (FCWT DASA 804-08-NTS-62)

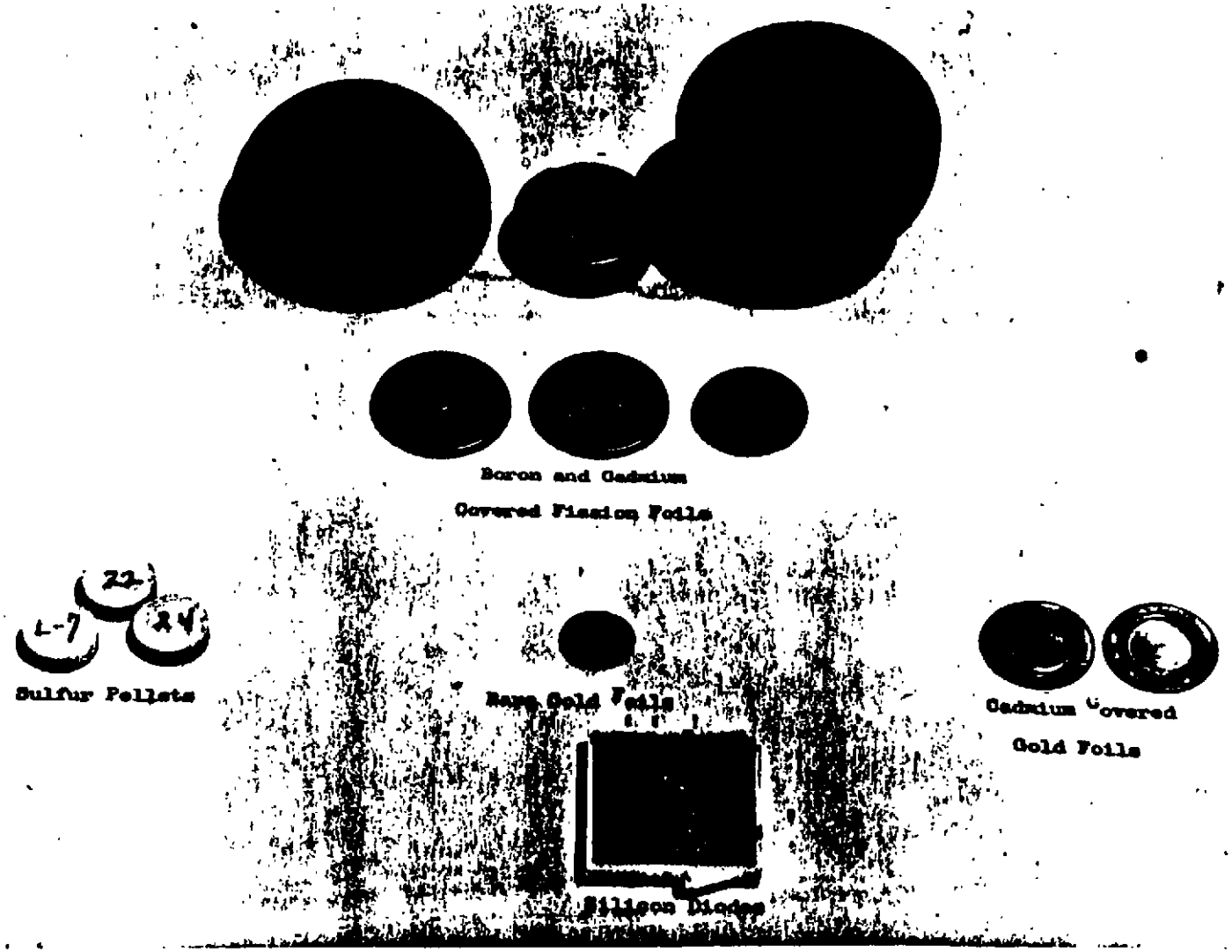

Figure 2 Neutron dosimeters. (FCWT DASA 804-09-NTS-62)

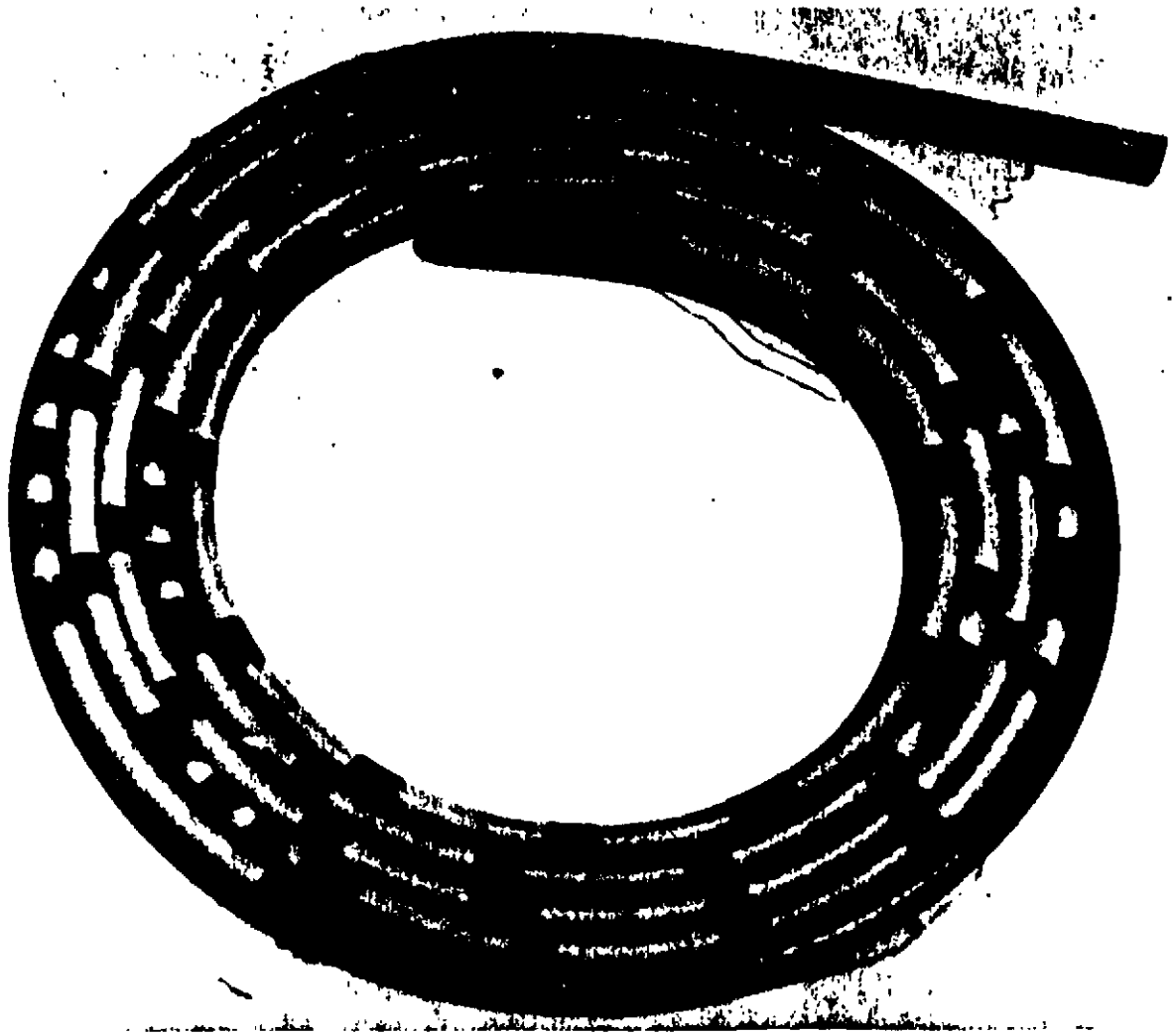

Figure 3 Polyethylene tubing containing fluorods. (FCWT DASA 804-07-NTS-62)

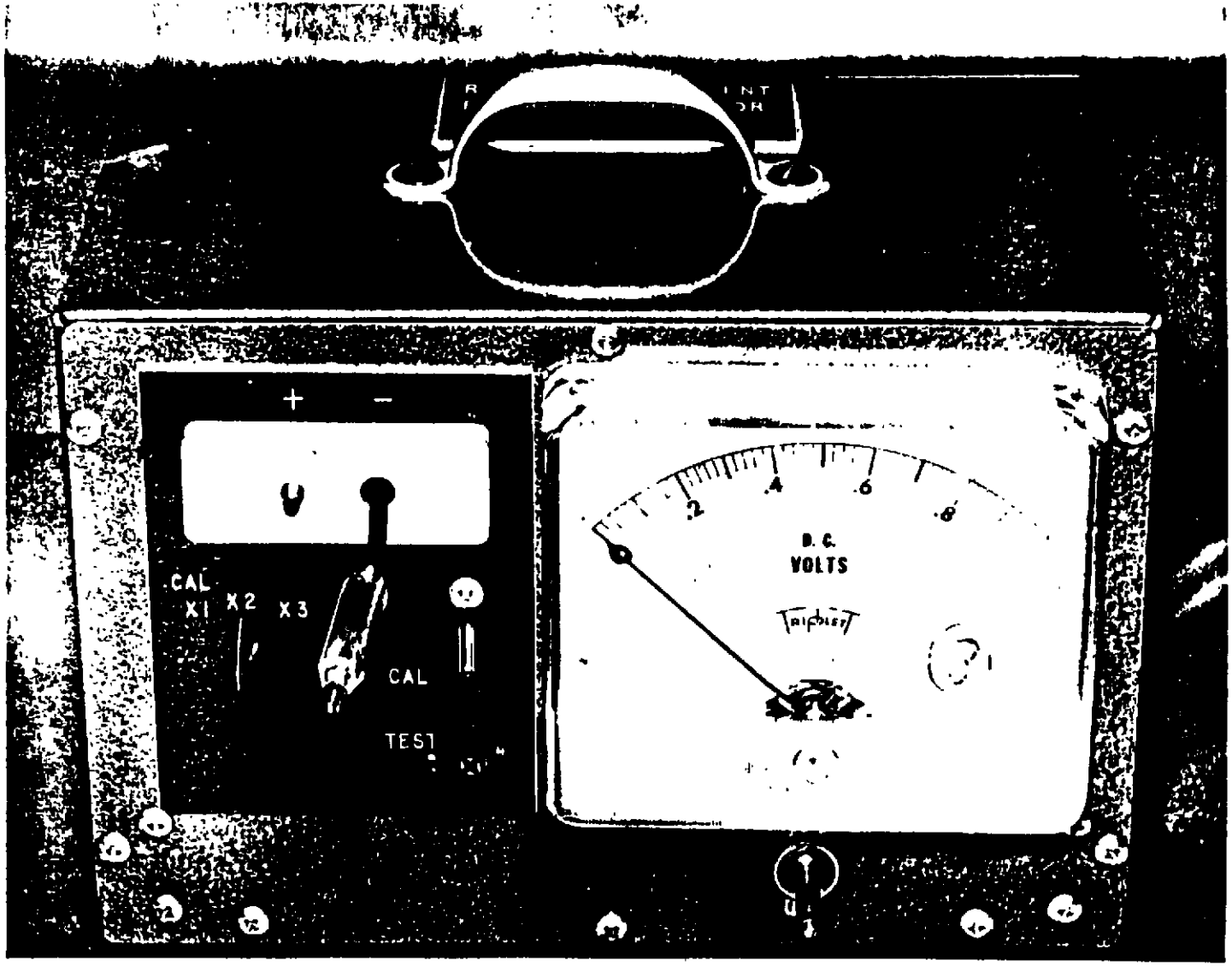

Figure 4 Silicon diode reader. (FCWT DASA 804-03-NT8-62)

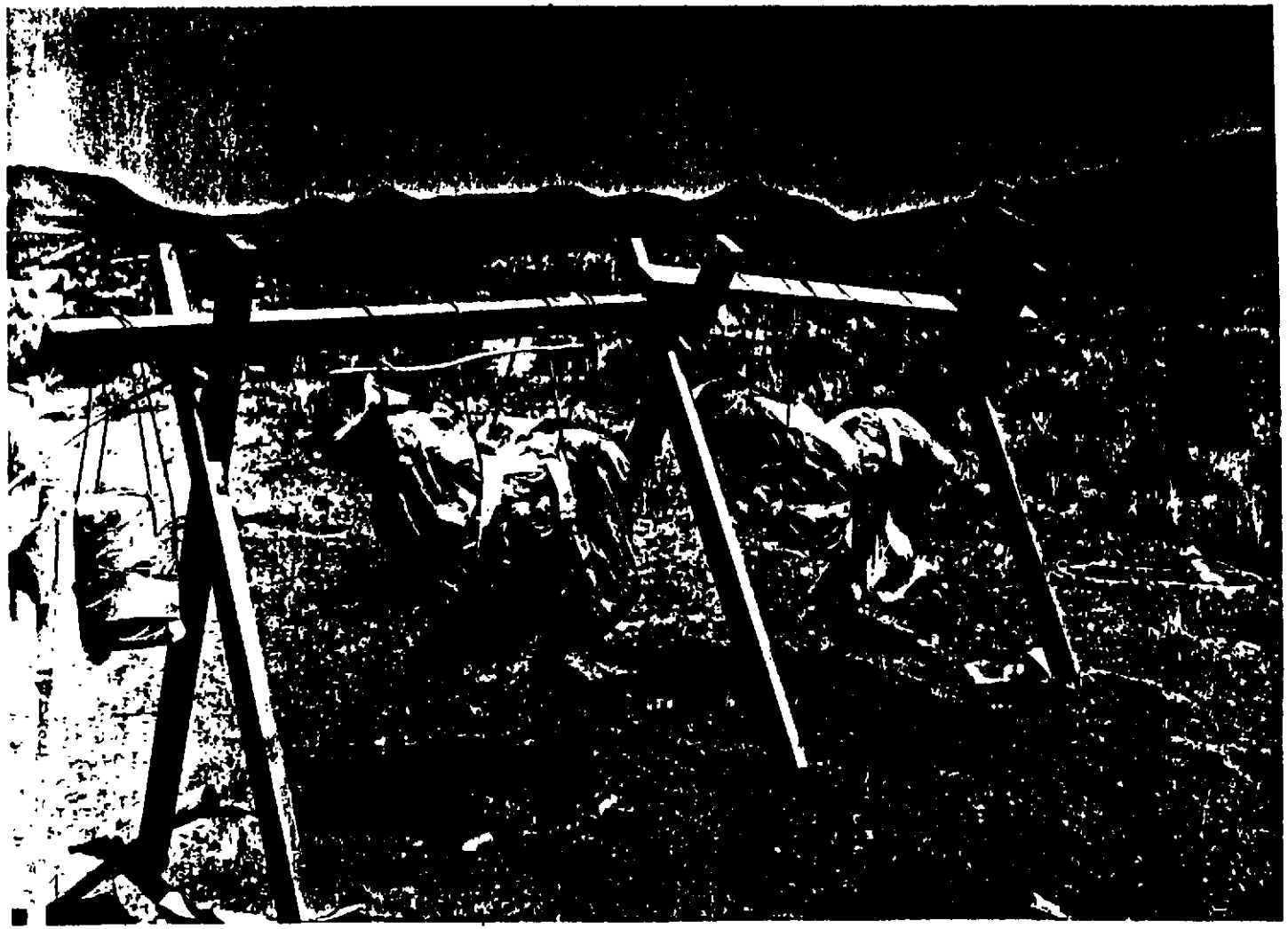

Figure 5 View of sheep and cylinders, Shot Little Feller II. (FCWT DASA 691-03-NTS-62)

Figure 6 View of plastinaut, Shot Little Feller II. (FCWT DASA 691-01-NTS-62)

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